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Invention Article

Innovative Photovoltaic Cooling System

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ABSTRACT

With the ever-increasing adoption of solar energy and the lack of space for PV installations, targeting maximum photovoltaic operational efficiencies has become essential. One of the key challenges faced by PV installations in warm climates is thermal management, which is caused by increasing temperatures due to PV conversion inefficiencies and limited ventilation possibilities in certain installations. Despite prior art, further improvement is still needed to provide a novel system that can offer more efficient and controllable temperature decrease of photovoltaic modules in both land and offshore installations. The present invention, termed IPCoSy, satisfies the aforementioned needs in the art by providing a novel system for cooling a solar panel assembly, including at least one photovoltaic module having a plurality of solar cells generating electrical power and a PV junction box attached to the back of the photovoltaic module. A part of this invention discloses a new type of PV module that is a modification of standard commercial modules. This new PV module incorporates a water chamber at the back of a solar cell assembly to regulate operational temperatures. Another part of this invention presents an after-market cooling system that can be fitted to existing standard PV modules to add the cooling effect. This part of the invention presents solid and flexible water tanks that can be fitted directly into a gap at the back of standard PV modules. Moreover, this invention presents details on parts that distinguish this cooling system from prior art, such as an internal stream spreader to obtain better fluid dynamics and external fittings that allow the PV module to be installed at any tilt angle without jeopardizing the cooling effect. Finally, this invention discloses different application areas of this cooling system, such as residential and industrial water heating, reverse osmosis plants and offshore photovoltaic installations, showcasing the product's versatility, adaptability and large market suitability.

Specifications Table

Specifications Table	
Subject code	2105 – Renewable Energy, Sustainability and the Environment
Specific subject area	Cooling system for PV modules; Combining hot water generation with renewable energy production through solar energy.
Industry code	H
Details of inventors	Ryan Bugeja (University of Malta, ryan.m.bugeja@um.edu.mt) Luciano Mule' Stagno (University of Malta, luciano.mule-stagno@um.edu.mt)
Dates of invention	Conception 2018 Disclosure 2021
Patent details	**Date patent granted:** 02/01/2023 **Patent owner:** University of Malta **Patent attorney or agent:** KOZLOVICH, Nick; REINHOLD COHN AND PARTNERS **Link to patent:** https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2023026274
Intended use	We intend to commercialize the technology and also use it for further research in the field.
Related research articles	R. Bugeja, L. Mule' Stagno, I. Niarchos, Photovoltaic Backside Cooling Using the Space Inside a Conventional Frame (IPCOSY), Future Energy 2 (3):20–28 (2023). https://doi.org/10.55670/fpll.fuen.2.3.3 R. Bugeja, L. Mule' Stagno, I. Niarchos, Full-Scale Design, Implementation and Testing of an Innovative Photovoltaic Cooling System (IPCoSy), Sustainability 15 (24),16,900

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Specifications Table	
	(2023). https://doi.org/10.3390/su152416900 R. Bugeja and L. M. Stagno, "Wave response modeling and innovative cooling technologies for offshore photovoltaics," 2023. Accessed: Jun. 04, 2024. [Online]. Available: https://www.um.edu.mt/library/oar/handle/123456789/119496
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1. Value of the invention

- This invention efficiently manages the operating temperatures of photovoltaic modules while wasting less pumping energy and prolonging the lifetime of the water pump.
- This invention can benefit both residential and industrial sectors, which aim to install photovoltaic modules and operate them at an increased efficiency.
- This invention can be combined with existing or new photovoltaic modules to manage their operating temperatures efficiently. Furthermore, it can be combined with residential or industrial water heating systems to increase the plant's efficiency.
- This invention can be combined with reverse osmosis plants to supply them with renewable energy while operating the PVs at an elevated efficiency.
- This invention provides a solution for cooling offshore photovoltaic installations without affecting the solar radiation absorbed by the solar cells.

2. Invention description

This invention, termed IPCoSy, involves a cooling system designed to reduce the operational temperature of photovoltaic (PV) modules while making it possible to use the extracted thermal energy for heating water. This innovative photovoltaic cooling system has many advantages of the prior art techniques while overcoming some disadvantages normally associated with PV cooling systems. This cooling system can result in a significant net electrical energy gain of more than 9 % and thermal efficiencies of up to 56 % [1–3]. For the configuration, when the installation is a closed system, the cooling system can operate with no extra water consumption. Furthermore, since the system is closed and water is in contact with the back of the PV modules, the water does not stain the front glass of the PVs [4]. This invention can be advantageous for offshore or floating photovoltaic installations due to unlimited water resources. However, this cooling system can also be used to aid in the water heating system of buildings, thus reducing net electrical consumption. It should be noted that this invention can also allow buildings to remove water storage tanks completely from their roofs, freeing up space and saving money. Manufacturing of this cooling system does not require any additional equipment to that already used in PV module manufacturing facilities. Moreover, installing the after-market cooling system to a PV module is relatively quick and easy. This can be accomplished without substantially altering the solar panel frame with which it is to be associated. These advantages make the present invention a durable, reliable and efficient PV cooling system.

The basic concept of this invention is shown in Fig. 1, with various parts labelled and numbered. The cooling system (100) includes a solar panel frame (18) that consists of a frame wall (181) having a panel holder (182) holding the solar panel assembly (101) at an upper part of the frame wall. Frame base ledges (183) project from opposite sides of the lower part of the frame wall along the length and/or width of the solar panel frame. The panel holder consists of a slot (180) formed by the upper (187) and lower (186) top frame ledges, adapted to hold the solar panel assembly.

The cooling system shown in Fig. 1 includes a bottom plate (3) hermetically attached to the frame base ledges to create a water chamber (2) directly underneath the backside of the solar panel assembly. This water chamber is defined by the back sheet of the PV module (102), the frame wall and the bottom plate. Examples of materials suitable for the bottom plate include but are not limited to, aluminum, stainless steel, polyethylene terephthalate (PET), Polypropylene and Polyimide. The water chamber has a water inlet (4) arranged in the frame wall at one end of the chamber and a water outlet (5) arranged in the frame wall at the opposite end of the chamber along the length of the frame. The cooling system also includes a temperature sensor (8) attached to the back sheet of the PV module to provide feedback to the cooling control system. The temperature sensor and the PV junction box (9) are attached to the back sheet of the PV module and are located within the water chamber intended to be filled with water. Therefore, these components are sealed using a waterproof material. The cooling system also includes an external PV junction box (10) mounted outside the water chamber, electrically connected to the PV junction box and the temperature sensor. The external PV junction box provides easy accessibility to the electrical terminals of the PV module and the temperature sensor in order to facilitate troubleshooting and maintenance.

The cooling system includes a stream spreader (7) arranged within the water chamber, as shown in Fig. 2. The stream spreader is hydraulically coupled to the inlet on the inner surface of the frame wall. This stream spreader is configured to provide a uniform fluid dynamic within the water chamber with the aim of pushing out the hot water with as little mixing as possible. The construction of the stream spreader involves an assembly of a T-elbow joint (71) connected to the water inlet at one end and two 45° elbow joints (72) connected to two other ends of the T-elbow joint, correspondingly. The openings of the two 45° elbow

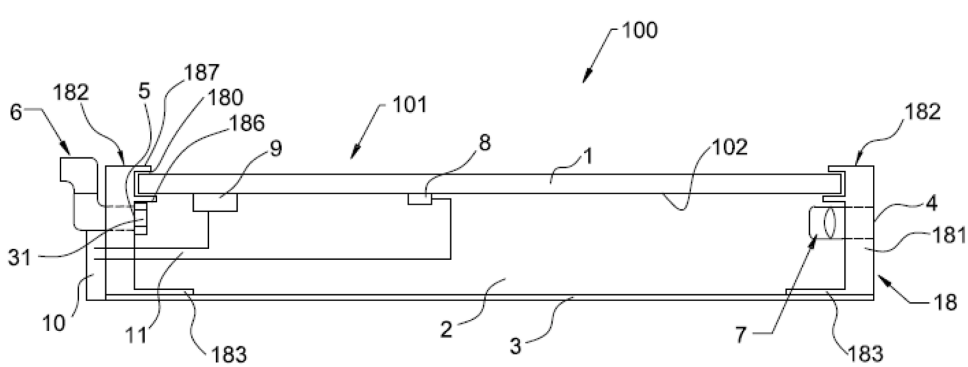

Fig. 1. Cross-section of an embodiment of the cooling system consisting of a modified PV module.

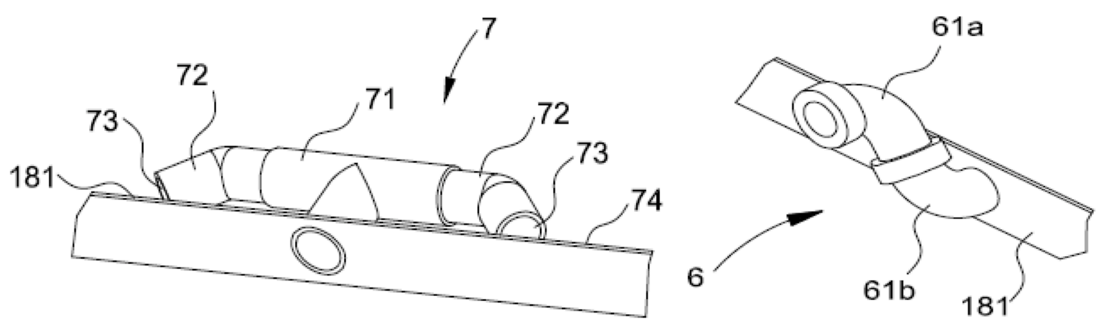

Fig. 2. Details on constructing the stream spreader and pipe adaptor forming part of the cooling system.

joints (73) are directed towards an inner face of the frame wall. Moreover, the cooling system includes a pipe adapter (6) hydraulically coupled to the water outlet on an outer surface of the frame wall. The pipe adapter is configured to provide freedom of movement of the solar panel assembly that is required for tilting the solar panel assembly. The pipe adapter can be manufactured from two 90° elbow joints (61a, 61b). An installation tilt angle of the PV module with respect to a surface of an installation platform is selected such that the solar radiation incident on the PV module(s) is optimised for the installation location and conditions. Hence, the pipe adapter can be rotated so that the water in the chamber is in complete contact with the back sheet of the PV module(s) independent from the installation angle, ensuring maximum heat transfer.

This invention also describes different ways in which the water chamber can be created, such as:

- attaching the bottom plate to an outer surface of the frame base ledges of the solar panel frame,
- attaching the bottom plate to an inner surface of the frame base ledges of the solar panel frame,
- connecting the frame base ledges, which project from the longitudinal sides of the solar panel frame to form the bottom plate. In this case, the bottom plate is a part of the frame wall.

Fig. 3 shows another possible configuration of the cooling system where the panel holder is a separate part of the frame wall tightly attached to the frame wall using fasteners. Examples of possible

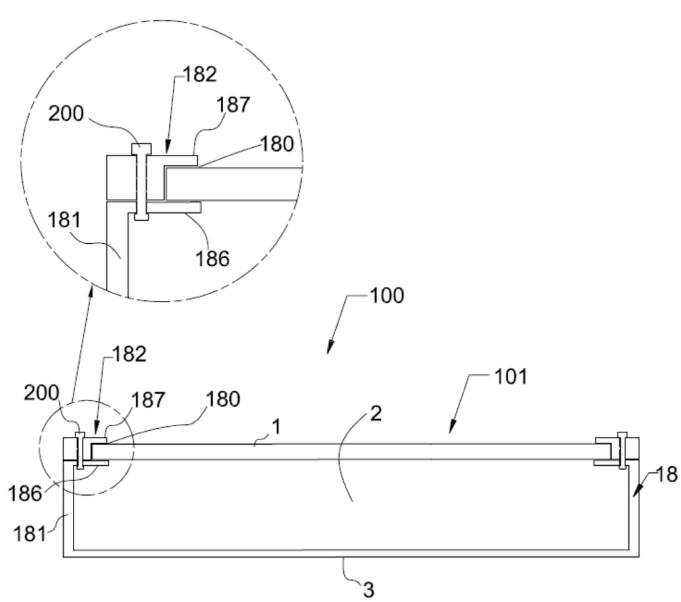

Fig. 3. An embodiment of the cooling system in which the solar panel assembly can be detached from the water chamber.

fasteners include but are not limited to, sealed blind rivets or Camloc™ fasteners.

The present invention also describes an after-market kit involving a solid (Fig. 4 TOP) or inflatable (Fig. 4 BOTTOM) tank fitted directly into a gap at the back of the solar panel frame. This allows cooling benefits to be added to an existing PV installation.

The cooling system described above can be implemented in several installation configurations. These include roofs of buildings where the cooling system can also be coupled with a water heating systems to increase efficiency. Furthermore, Fig. 5 shows that this invention can also be coupled with a water storage tank (19) installed on an installation surface (20). A water pump (12) creates a flow from the water storage tank through the cooling system. A control unit (14) monitors feedback from temperature sensors and hence uses an algorithm to control the operation of the water pump. This installation configuration also includes a one-way valve (13) located within the manifold between the water storage tank and the water pump, thereby ensuring that the water chamber remains filled with water permanently even when the water pump is switched off.

The cooling system described in this invention is also ideal for floating photovoltaic installations installed on a water body such as lakes or the sea. Similar to the installation described above, the cooling system includes a controllable water pump hydraulically coupled to the water inlet through a manifold. The water pump is configured to controllably pump water from the water body to the water chamber through the cooling system's water inlet while pushing the heated water inside the water chamber through a water release pipe. This configuration allows for the cooling of offshore PV modules without interfering with the absorption of solar radiation, as would happen with front-side cooling due to salt deposition.

Fig. 6 shows another installation configuration of this cooling system involving its integration with a reverse osmosis plant. In this case, the cooling system is installed on a platform (15) mounted on water or coastal land at a predetermined installation angle with respect to a surface of the platform. The water inlet of the cooling system is hydraulically coupled to the reverse osmosis plant (35) configured to receive water from the sea (16). This installation would power the reverse osmosis plant using renewable energy and enable the PV modules to operate more efficiently while using the existing water flow required for the reverse osmosis process.

3. Application potential

This solution has wide market applicability as it is attractive to anyone wishing to operate photovoltaic panels at their maximum potential. Furthermore, this solution can increase electricity output from solar energy while providing heated water. Therefore, if used in plants with water boilers, this system will generate electricity and improve the overall efficiency of the plant's water heating system. However, the control algorithm needs to be calibrated to get a positive net energy gain when considering the energy consumed by the water pump. This invention excels even more in areas where a water flow is already present

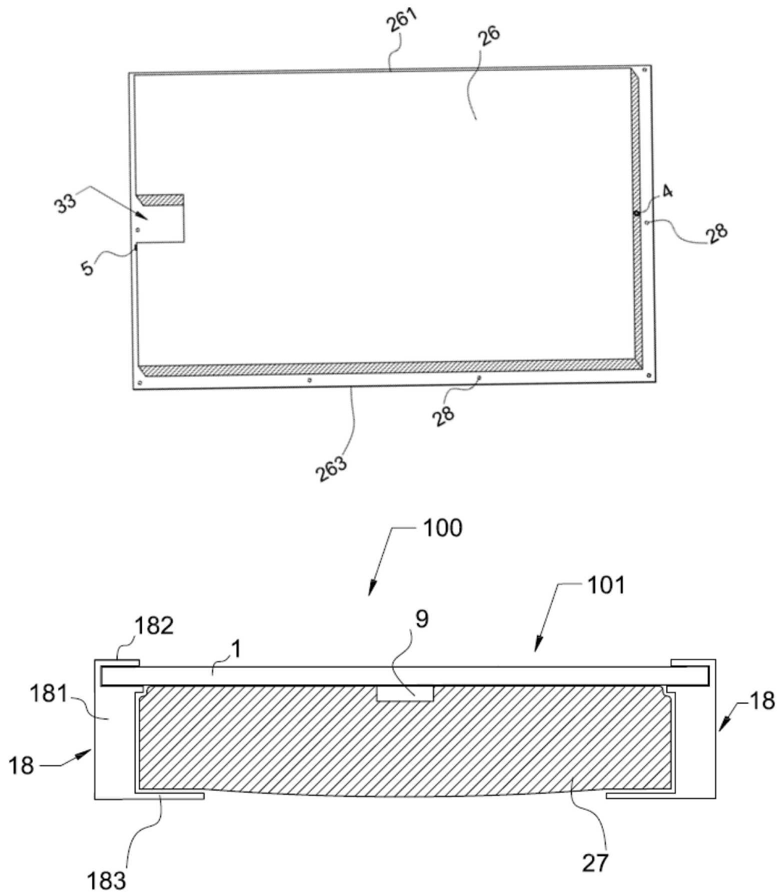

Fig. 4. After-market kit involving a solid (TOP) or an inflatable (BOTTOM) water tank.

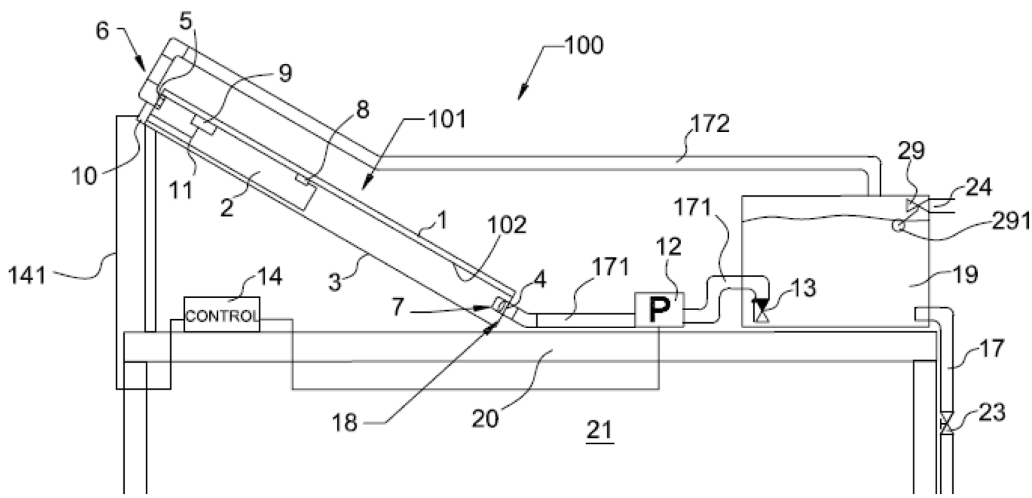

Fig. 5. Cooling system coupled with a water storage tank.

for other processes, such as reverse osmosis plants. In such plants, the IPCoSy modules will supply electrical energy from a renewable source while using the existing water flow to increase the operational efficiency of the PV modules. Finally, this cooling system is adequate for offshore photovoltaic installations since it does not stain the front glass of the PV modules, which could lead to reduced light transmission and, as a result, a lower generation efficiency.

Ethics statements

No specific ethics statement.

CRediT authorship contribution statement

Ryan Bugeja: Writing – original draft, Methodology, Investigation, Funding acquisition, Conceptualization. **Luciano Mule' Stagno:** Writing – review & editing, Validation, Supervision, Resources, Investigation, Funding acquisition.

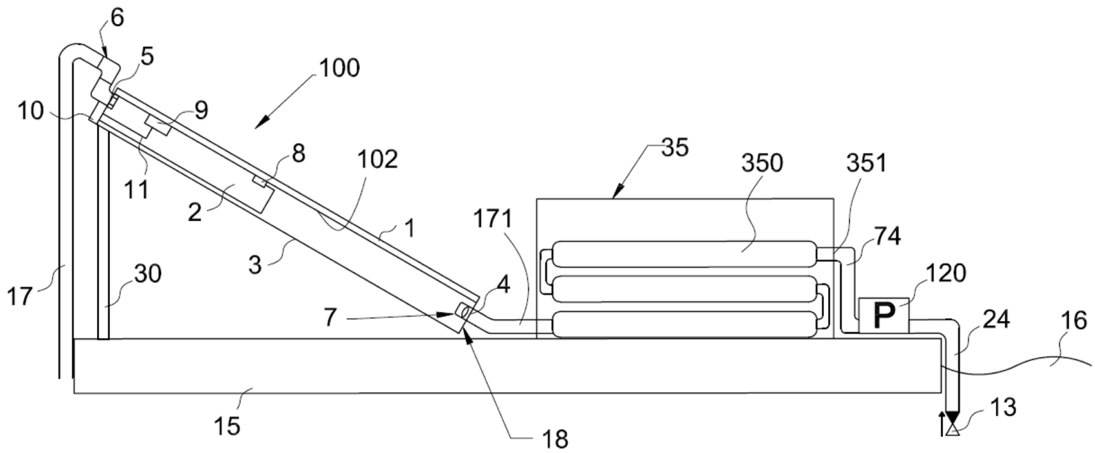

Fig. 6. Cooling system coupled with a reverse osmosis plant.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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